Semi-Annual Progress Report

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Task Objectives

The objectives of the last six months were:

- Revise the algorithms for the Fluorescence Line Height (FLH) and Chlorophyll Fluorescence Efficiency (CFE) products, especially the data quality flags
- Revise the MOCEAN validation plan
- Deploy and recover bio-optical instrumentation at the Hawaii Ocean Time-series (HOT) site as part of the Joint Global Ocean Flux Study (JGOFS)
- Prepare for field work in the Antarctic Polar Frontal Zone as part of JGOFS
- Submit manuscript on bio-optical time scales as estimated from Lagrangian drifters
- Conduct chemostat experiments on fluorescence
- Interface with the Global Imager (GLI) science team
- Continue development of advanced data system browser

Work Accomplished

Revisions of CFE and FLH Code

We are responsible for the delivery of two at-launch products for AM-1: Fluorescence line height (FLH) and chlorophyll fluorescence efficiency (CFE). As noted in our last report, we have decided to keep the FLH and CFE algorithms integrated as single piece of code. We also considered revising the input chlorophyll, which is used to determine the degree of binning. Based on studies by Ken Carder and Dennis Clark, we have decided to retain the chlorophyll derived by Carder which is based on reflectance. These studies indicate that there is no significant difference between the Carder approach and the water-leaving radiance approach used by Clark.

We have refined the quality flags for the Version 2 algorithms. These flags are based in part of specific values of input products, and these have been delivered to the University of Miami for integration.

We have acquired and installed a Silicon Graphics Origin 200 that will host the MOCEAN software as it is delivered to the EOSDIS Core System Project at Goddard. This will allow us to produce various research products using the basic MOCEAN processing suite.

We are working with the University of Miami team to develop documentation that will describe how the MODIS ocean components are linked together. This document will provide more detail than the individual ATBDs and will describe the data flows and dependencies. Ms. Jasmine Bartlett (who was hired as part of my GLI work) has analyzed all of the oceans ATBDs and has scheduled a visit to Miami to begin this documentation process.

MOCEAN Validation Plan

Our role in the MOCEAN validation remains based on characterization of FLH and CFE in several “end-member” environments, and quantification of the temporal and spatial scales of these products. The first part will provide quantitative limits on the variability of the FLH and CFE, and the relationship of this environmental variability to environmental and physiological factors. That is, although high signal to noise ratios are required for MODIS to make meaningful measurements of chlorophyll fluorescence in the open ocean, the most significant challenge is the interpretation of fluorescence-based products in the context of phytoplankton physiology. Second, we have quantified the time and space scales of variability of fluorescence in the California Current, and we are preparing for similar studies in the Southern Ocean. These estimates will be used to develop quality assurance tests as well as to develop rigorous tests for product validation.

Characterization of variability of FLH and CFE is relying on both field and laboratory studies. The field work in the California Current System has resulted in a manuscript that has been submitted to *Deep-Sea Research* which is included in the appendix of this report (without figures). These results are summarized below. We are continuing field work at the HOT site, which will be discussed later, and our field program in the Southern Ocean will begin in October 1997. We have acquired a Tethered Spectral Radiometer Buoy II from Satlantic that measures 7 channels of upwelling radiance and 7 channels of downwelling irradiance. The TSRB II will be used in the Southern Ocean for validation of the optical measurements from the bio-optical moorings. Our Fast Repetition Rate (FRR) fluorometer has finally been delivered. It will be first tested on a cruise this September off the coast of Oregon. It will then be used as part of our Southern Ocean work as well as in laboratory measurements. The laboratory work is based on chemostat work that has been discussed in earlier reports. A significant change in our plan has occurred, though, as we are now actively collaborating with Dr. Dale Kiefer (University of Southern California) who is one of the pioneers in the study of phytoplankton fluorescence. We have acquired Dr. Kiefer's specially-built chemostat which incorporates precision optics to stimulate and measure chlorophyll fluorescence in phytoplankton cultures. This device is being used to study the fluorescence response of different phytoplankton species to changing levels of nutrients and light.

Measurements of fluorescence have been collected using the Airborne Oceanographic Lidar (AOL) operated by Frank Hoge. These measurements have been used to calculate FLH, although the band placement is somewhat different than MODIS. The FLH measurements compare favorably with the laser-induced fluorescence measurements from the AOL. These data were collected over the Gulf Stream region where chlorophyll exceed 1.0 mg/m^3. We expect to work with Hoge on similar aircraft measurements as part of the MODIS Oceans team validation campaigns.

Hawaii Ocean Time-series Mooring

As part of the U.S. Joint Global Ocean Flux Study (JGOFS), the Hawaii Ocean Time-series (HOT) program has been making monthly measurements of biogeochemical and physical processes north of Oahu at Station Aloha. In January 1997, the HOT group established a permanent mooring at a site just to the south of Station Aloha, named Hale Aloha. The mooring at Hale Aloha includes a full array of physical and chemical samplers, and we attached a spectroradiometer at 25m depth. The mooring was serviced in May 1997 and redeployed. We have also acquired a second system that will be moored at 50m depth in January 1998.

The mooring was designed to provide insight into short time scale processes that cannot be adequately resolved by monthly ship sampling. Figure 1 shows the temperature record collected by the mooring. Note the sudden upwelling that begins in early March, as evidenced by the doming of the isotherms. This event persists for over 40 days. The monthly ship sampling showed a dramatic increase in the amount of nitrate in the upper ocean, with a nearly two order of magnitude increase. Such an event was initially thought to be a mesoscale eddy, which were suspected to be an important component in the nutrient budget in the oligotrophic central gyres. The bio-optical signals are shown in Figures 2 and 3. Note that chlorophyll nearly triples in response to this event, but that the response does not begin until about 20 days after the physical signal is first detected. The "bloom" in chlorophyll lasts about 20 days. However, the colored dissolved organic matter (CDOM) content and the apparent quantum yield of fluorescence signals begin to change at the beginning of the upwelling event. CDOM peaks just before chlorophyll reaches its peak, while the quantum yield of fluorescence first increases, then decreases, and then increases again as the event ends. We interpret these patterns as follows. The initial upwelling event brings up nutrient-rich water that is also higher in CDOM than the surface waters where photolysis of CDOM occurs. The phytoplankton in these deeper waters are also light-limited, so their initial response is to increase the quantum yield of fluorescence. Eventually, the system adapts to this new physical environment, and phytoplankton photosynthesis increases (as evidenced by the decrease in fluorescence quantum yield). As the bloom begins to exhaust the upwelled nutrients, the quantum yield of fluorescence again increases.

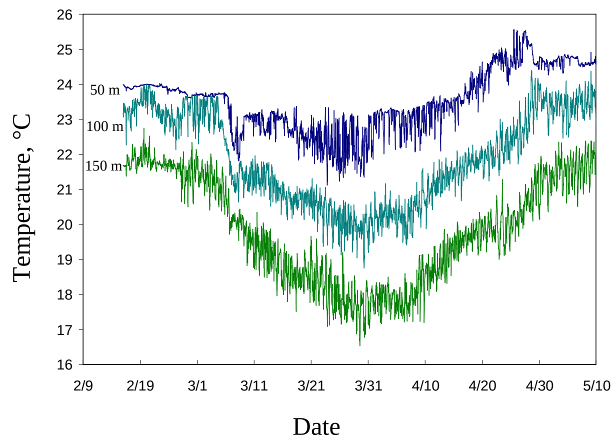

Figure 1. Plot of temperature from three depths at the Hale ALOHA mooring north of Oahu.

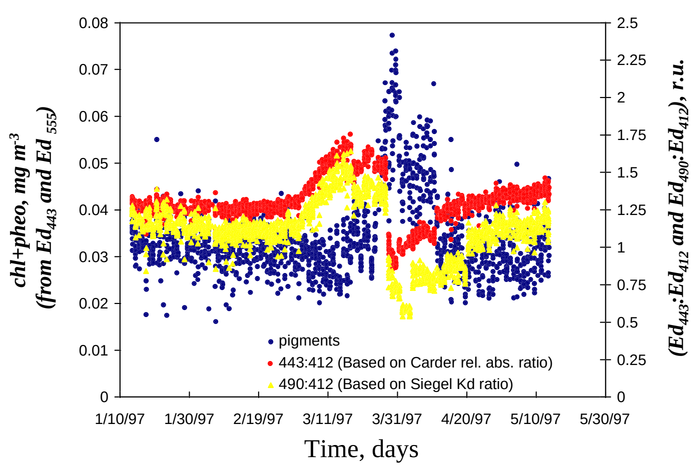

Figure 2. Time series of chlorophyll and CDOM from the Hale ALOHA mooring

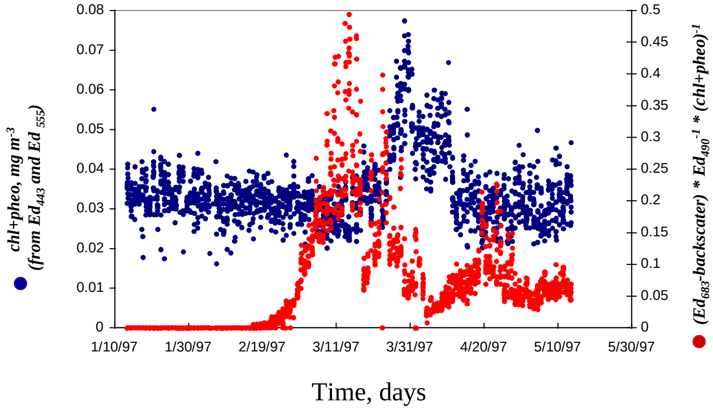

Figure 3. Time series of chlorophyll and apparent quantum yield of fluorescence. Note that the data logger failed during the first part of the deployment for the fluorescence channel, and then began to work properly in mid-February.

In collaboration with Michael Freilich, we have compared these data sets with the two-dimensional wind velocity fields derived from NSCAT. Ekman pumping, which results from the time-dependent changes in the divergence field of the wind stress, correlates extremely well with the onset of the upwelling event (as well as a smaller event in January). These changes in the field in January and early March are also correlated with two westerly wind bursts that occurred in the western tropical Pacific this year, as part of the developing ENSO event. The surprising fact is that oceanographers have long assumed that ENSO responses in the eastern Pacific were driven by “remote” forcing. That is, changes in the wind field in the western Pacific were propagated eastward through the ocean by Kelvin waves. The time scale for these waves is on the order of 60 days. However, these results suggest that the “remote” forcing may actually be “local.” Changes in the western Pacific winds may propagate rapidly eastward through the atmosphere, changing the local wind fields which in turn drives the ocean response.

Of note to MODIS, though, is the need for high resolution time series for validation. Occasional ship cruises can provide data at a level of detail that cannot be obtained any other way. However, their episodic nature means that critical processes may be missed. Validation will continue to require moorings, drifters, and ship studies.

Antarctic Polar Frontal Zone Study

As we have discussed in earlier reports, we will deploy 12 bio-optical moorings and 15 bio-optical drifters in the Antarctic Polar Frontal Zone as part of the JGOFS Antarctic Environment Southern Ocean Process Study (AESOPS). The bulk of the funding is from the National Science Foundation, but NASA/MODIS funding has provided some of the instrumentation and drifters.

We have now assembled all of the sensors, and a test deployment was conducted successfully off the Oregon coast. The cost for each mooring (including spectroradiometer, current meter, conductivity sensor, and all mooring hardware) is less than $20,000. This is about one order of magnitude less than traditional moorings. This lightweight, low cost design will allow us to study mesoscale processes at a spatial resolution that has not previously been achieved in the Southern Ocean.

In our last report, we mentioned the three bio-optical drifters that were deployed in the APFZ in September 1996. All three drifters have ceased operation, and we have completed initial screening and quality control of the data. These optical measurements will be provided to the OCTS and POLDER teams as well as to the SIMBIOS Project at GSFC.

Bio-Optical time Scales

As mentioned earlier, we have submitted a manuscript on the time scales of chlorophyll and fluorescence in the California Current System. A copy of the manuscript is attached. Briefly, the results show that the combination of chlorophyll and fluorescence data can be used not only to estimate biomass and productivity rates, but that the patterns of the temporal decorrelation scales can be used to infer types of ecological strategies. Specifically, nearshore communities have significantly different time scales for both biomass and fluorescence. Offshore, these time scales are nearly identical. This suggests that the nearshore community has photosynthetic properties that are not in balance with their light-harvesting ability (as revealed by chlorophyll) whereas the community offshore is more nearly in balance. Non-equilibrium strategies may be especially advantageous in the more episodic regime of the nearshore region, whereas offshore communities may be closer to equilibrium in a more "even" physical environment. Therefore MODIS fluorescence data may be useful from an ecological perspective as well.

A second manuscript entitled "Going with the flow - The use of optical drifters to study phytoplankton dynamics," is in press in *Monitoring Algal Blooms: New techniques for Detecting Large-Scale Environmental Change* (M. Kahru and C.W. Brown, editors).

GLI Activities

In collaboration with the National Space Development Agency of Japan (NASDA), we have hired Ms. Jasmine Bartlett to coordinate the interactions between the MODIS Oceans team and the GLI Oceans team. Dr. Janet Campbell represented the MODIS Oceans team at a recent ADEOS II workshop held in Japan. We have provided the GLI team with the latest ATBDs, and we are now developing documentation on the overall structure of the MODIS Oceans algorithm code. We have met with Bob Evans and mapped out a strategy to produce this document. Ms. Bartlett will spend 2 weeks in Miami this fall, documenting the data flows and the code dependencies. The final document will be provided to NASDA and the MODIS Science Data Support Team. We will also deliver the V2 MODIS Oceans algorithm package to the GLI team after it has been delivered to EOSDIS.

EOSDIS Plans

We continue to develop our web-based system to access, manipulate, and visualize data using both Java and ActiveX. This activity is funded by both MODIS and Hughes. Technical reports on these activities were provided to Ed Masuoka of the MODIS SDST.

Rather than describe both activities in detail, we will summarize the Java activity. However, both the ActiveX and Java development efforts are proceeding in parallel, so the information presented here applies equally to the ActiveX effort.

We are currently using Java applets to access data stored in our relational data base system as well as provide analysis and visualization capabilities. These applets operate in a browser-centric environment, where the architecture is three-tier. The first tier is made up of the applets. The second tier is made up of the application servers (for computation, etc.), and the third tier is the relational data base. The main technologies used by the applets are *Java Data Base Connectivity* (JDBC) and *Java Remote Method Invocation* (RMI). The first provides platform-independent access to our Microsoft SQL Server data base running under NT Server 4.0. The second provides an infrastructure for distributed object communication.

The present functionality of the system includes:

- Access to ocean drifter data
- Retrieval of coastline data for overlay
- Retrieval of corresponding satellite imagery
- Extraction of data from images
- Image customization (zooming, color maps, etc.)
- Overlay of tracks on images in time and space
- Comparison of imagery and drifter data

- Animations

We have now extended this approach through the use of a component object model for Java known as *Java Beans*. This enables the creation of reusable software components (known as *beans*) which are more lightweight than Java applets. These beans can be assembled together using visual application builders (for example, drawing a line to link two beans together). These beans can run inside Microsoft containers such as Visual Basic. Our new system design is based on this component model such that:

- The user need not be concerned with data base structure
- Algorithms may be applied as data are retrieved from the data base
- Software components may be able to be linked together
- The component state can be saved for later modification.

We have divided the system into *client side* and *server side* components. On the client side:

- Data viewer component which will not expose the structure of the data base
- Drifter analysis component
- Image viewer and analysis components
- 3D data viewing component, such as NOAA hydrographic data.

Server side components include:

- Data base access component which would retrieve data and present it to other requesting components. It would also support application of algorithms to retrieved data
- Component to encapsulate functionality of MATLAB in Java and interact with other components requiring the capabilities of MATLAB
- Computation components.

Both client side and server side components have been implemented as Java Beans. The server side components appear to the client side components as remote objects providing services. Hence the RMI capabilities are used to link the client and server side components. The client side components are tools that may be composed together visually, as discussed earlier. The beans may also be programmed together into an applet that can be used in a Web page. The beans may exchange data through the use of events. We have also developed a way to save the state of the beans (persistence) so that a user can retrieve an earlier analysis project and continue it.

Although the capabilities of Java have increased substantially in the last year, many of these capabilities have been present for many years in Microsoft's Distributed Component Object Model (DCOM) which is at the heart of ActiveX. DCOM has a far richer set of classes and application development tools. In addition, Java capabilities will be incorporated into DCOM so that the two will interoperate.

Anticipated Future Actions

- Retrieve and redeploy bio-optical mooring in Hawaii and continue analysis of bio-optical data
- Deploy bio-optical moorings and drifters, TSRB II, and FRR in the Antarctic Polar Frontal Zone
- Continue chemostat experiments on the relationship of fluorescence quantum yield to environmental factors. Establish relationship between fluorescence quantum yield and photosynthetic parameters.
- Deliver V2 code and documentation to GLI oceans team and define integration issues.
- Continue to develop and expand browser-based information system for in situ bio-optical data.

Problems and Solutions

The most significant concern now is the apparent inability of EOSDIS to deliver data products at launch. The present approach to cost-savings is based on scaling back hardware acquisitions, which has been shown to be a small fraction of the overall EOSDIS budget. Thus the approach mandated by NASA Headquarters will likely not save money while at the same time causing deep frustration in both the EOS and general Earth science communities.

Appendix

Manuscript submitted to *Deep-Sea Research*; figures have not been included with the manuscript.